The Oregon Water Conference 2011: Evaluating and Managing Water Resources in a Climate of Uncertainty
Oregon State University – CH2M Hill Alumni Center – Corvallis, Oregon
OR Chapter, American Water Resources Association and OR Section, American Institute of Hydrology

What Will Oregon's Future Streamflow Regimes Look Like? Integrating Snowpack and Groundwater Dynamics.

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ABSTRACT

Spatial patterns of summer streamflow in the Cascade Mountains of Oregon vary dramatically between the geologically distinct High and Western Cascade regions. A key control is the partitioning of water input between a fast-draining shallow subsurface flow network (Western Cascades) versus a slow-draining deeper groundwater system (High Cascades). These differences result from large contrasts in rock permeability, porosity, and drainage density between landscapes dominated by the older Western Cascade versus younger High Cascade volcanic rocks.

How do these geologically-based differences in groundwater storage capacity affect streamflow response to projected climatic warming? We initially expected that for the High Cascades of Oregon and Northern California, large groundwater storage will lead to groundwater recharge independent of precipitation type (rain or snow), thereby buffering low flows against potential changes in snowpack volume due to warming climate. We also expected that low groundwater storage in the older volcanic and granitic landscapes of Oregon and California will result in greater sensitivity to diminished snowpacks and summer streamflow changes.

By coupling simple theory with hydrologic modeling, we found that interpreting low flow response to warming involves a convolution of both the snowpack and groundwater dynamics. Using this approach, the High Cascades displays much greater low flow sensitivity to climate change than the Western Cascades. Because the High Cascades discharge groundwater throughout the summer season, both timing of recession and annual fluctuations in total precipitation are reflected in changes in late summer streamflow. The Western Cascades in contrast, displays much less late season sensitivity to changing climate; streamflow is always very low in late summer regardless of winter recharge. We extend these results across the entire western Cordillera and consider implications for water supply in the future. These results imply that current models linking climate and streamflow changes need to account for differences in groundwater storage as a first-order control.

Keywords: Streamflow; Oregon; Climate Warming; Snowpack; Dynamics; Groundwater

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Sensitivity of Oregon Watersheds to Streamflow Changes Due to Climate Warming: A Geohydrological Approach

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ABSTRACT

A key challenge for resource and landscape managers is to predict the consequences of climate warming on streamflows and water resources. Different approaches are being developed to forecast the direction, magnitude, and timing of future streamflow changes in specific landscapes. One approach that is being utilized in the Pacific Northwest involves coupling downscaled climate predictions to macroscale hydrologic models, such as the Variable Infiltration Capacity (VIC) model. VIC is typically parameterized and calibrated in selected watersheds, and then applied to a regional scale that includes larger population of uncalibrated watersheds.

Summer streamflows are sensitive to both changes in the timing of snowpack accumulation and melt, and intrinsic, geologically-mediated differences in the efficiency of landscapes in transforming recharge (either as rain or snow) into discharge. Here we explore the importance of this effect by using geologically focused "bottom-up" approach to empirically characterize the sensitivity of late-summer streamflows to climate warming for a range of basins across Oregon. We define sensitivity as the slope of the relation between annual precipitation and summer streamflow, characterized as 7-day low flow and total summer flow. Drainage efficiency was defined in terms of the: 1) rate of recession (K) of the streamflow hydrograph; and 2) ratio of base flow to total flow (Base Flow Index or BFI). We compare our sensitivity results with those derived from VIC simulated streamflow.

Using the bottom-up approach, we found that the both K and BFI are good predictors for streamflow sensitivity to climate change. Fast-draining basins (high K / low BFI) are much less sensitive to changes in annual precipitation, whereas slow-draining basins (low K / high BFI) are much more sensitive. For basins where VIC was calibrated, downscaled VIC simulations are similar to empirical data. Uncalibrated basins, however, do not show a clear relationship with drainage efficiency, meaning that VIC may under predict sensitivity of summer stramflows to climate change in uncalibrated groundwater-dominated watersheds. This implies that spatial heterogeneity in aquifer properties must be explicitly incorporated into parameterization and calibration schemes if the full range of hydrologic response to warming is to be captured across the landscape.

Keywords: Climate change: Geologic framework, Streamflow

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Coupled Simulation and Optimization Models for Managing Groundwater in the Upper Klamath Basin, Oregon and California

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ABSTRACT

Managing limited surface water in the Klamath Basin of Oregon and California to satisfy needs of both agriculture and aquatic wildlife has been a challenge for resource managers in recent years, as well as a source of considerable contention. In the past decade, groundwater has been used (heavily at times) to supplement overtaxed surface water supplies, and groundwater use is being considered as part of a long-term water management strategy. Supplemental groundwater pumping, however, has the potential to diminish already stressed surface water supplies and to result in seasonal and long-term groundwater level declines.

Developing a groundwater management strategy, therefore, requires the ability to predict the temporal and spatial distribution of pumping-related drawdown and impacts to hydrologic boundaries such as streams, springs, lakes, wetlands, and agricultural drains. Also required is a method for efficiently determining the optimal groundwater pumping strategy with which to meet resource management objectives without causing impacts that are unacceptable to the community or in violation of water law.

To meet this need, the U.S. Geological Survey and the Oregon Water Resources Department have collaboratively developed a regional groundwater flow model of the 8,000 square mile upper Klamath Basin and a coupled groundwater management model that employs methods of constrained optimization. Initial work has provided information on the tradeoffs between pumping volumes, seasonal and long-term drawdown, and impacts to surface water, and suggests that useful volumes of groundwater can probably be pumped with minimal interference with existing uses. Initial work has also quantified impacts to agricultural drains (which are water sources for some irrigators and wildlife refuges) that may represent an unanticipated, and not fully understood, constraint on groundwater pumping.

Keywords: Groundwater modeling; Groundwater management, Optimization, Klamath Basin

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Climate Change Impact on Drought Risk and Uncertainty in the Willamette River Basin

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ABSTRACT

Climate change due to global warming could induce more frequent droughts in the Willamette River Basin because less snowfall in winter and earlier snowmelt due to temperature increase may lead to decreases in spring and summer streamflow. This study examines possible changes in drought risk using two drought indices, Standardized Precipitation Index (SPI) and Standardized Runoff Index (SRI). SPI represents a climatological drought index that considers only precipitation change, while SRI is a hydrological drought index that considers water balance change. In rainfall-dominated regions in the Willamette Valley, SPI is a useful drought index. In snow-dominated regions in the High Cascades, SRI can show more realistic drought risk change because SRI can represent snowmelt and geology effects.

Our results show that the Willamette Valley is more vulnerable to drought risk than the High Cascades in the 21st century. SPI shows increasing frequency and intensity of short-term drought over the whole Willamette River basin due to summer precipitation decrease, while SRI in the High Cascades shows no change because the High Cascades have young permeable volcanic rocks and gentle slopes, which create a deep groundwater system. Additionally, the frequency of short-term extreme drought, such as droughts lasting 1 to 3 months, is projected to increase in the Willamette Valley, but long-term extreme droughts are not expected to change significantly. The increase in short-term extreme droughts is attributed to decreases in summer precipitation, and the lack of change in long-term extreme droughts is caused by increased winter runoff prompted by earlier snowmelt and winter precipitation increases.

Keywords: Drought; Climate change; SPI; SRI; Uncertainty; Willamette River; Oregon

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Assessment of the Hydrologic Response to Climate Change in the Upper Deschutes River Basin, Central Oregon

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ABSTRACT

Effects of climate change in the Cascade Range will likely include more rain, less snow, and earlier snowmelt in the Cascade Range as compared to present conditions. These changes, in turn, will affect the timing of runoff, groundwater recharge, and groundwater discharge to spring-fed streams. This hydrologic response needs to be examined and understood due to implications for water management.

In this study, a water- and energy-balance model was used to explore 21st century changes in the water budget in the upper Deschutes Basin, and a groundwater model was used to evaluate the response of the groundwater system to those changes. A Deep Percolation Model (DPM) developed for the basin in the 1990s uses spatially distributed climate data to calculate a daily mass balance for the major components of the hydrologic budget. For this work, we drove the DPM using ensemble means of eight downscaled global climate models with the Intergovernmental Panel on Climate Change's A1B and B1 emission scenarios.

Although similar for both scenarios, greater changes in the timing of runoff and recharge as well as higher reductions in snowpack occur using the A1B scenario. Considering both scenarios, diminished snowpack results in reductions in spring runoff ranging from 40% to 63% and recharge from 21% to 37%. These reductions are offset by late fall and winter increases. Also, spatial changes in the mean annual ratio of recharge to runoff occur due to changes in soil infiltration rates.

The modeled response of the groundwater system to changes in the time and amount of recharge varies spatially. Short flow-path systems in the upper part of the basin are most sensitive to change in seasonality of recharge. At regional scales, diffusion along groundwater flow paths partially attenuates the effects of changes in recharge timing. Furthermore, slight increases in total annual groundwater discharge to smaller streams in the upper portion of the basin, and slight decreases in discharge to larger stream systems in the north-central portion of the basin are projected.

Keywords: Groundwater; Hydrology; Climate change; Global Climate Model (GCM)

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Climate Change and Oregon's Water Future

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ABSTRACT

The specter of climate change looms large over Oregon. Although hydroclimatologic models predict a warmer Oregon, the total volume of precipitation may not change significantly. However, the character (rain vs. snow) and spatial and temporal distributions of precipitation will likely change. The state is already witnessing earlier snowmelt in the Oregon Cascade Range. Much of the Cascade snowpack occurs at relatively low elevations and is thus very sensitive to even slight temperature changes. Earlier than normal snowmelt can produce unseasonal flooding and landslides and lead to storage problems since the snowpack provides natural 'free' storage. Without additional storage the resulting reduced summer runoff will likely produce: water shortages; insufficient flows to dilute waste and for environmental needs; higher stream temperatures and reduced dissolved oxygen levels; increased aquatic invasive species; and reductions in hydroelectric power generation. Reduced streamflows may lead to increase usage of nonrenewable groundwater. The effects on groundwater recharge are unclear.

Oregon must now adapt to prepare for a potentially water-stressed future by: 1) further investigating the potential for aquifer storage recovery and artificial recharge (ASR & AR); 2) assessing its surface water and groundwater supplies; 3) ensuring that climate change is incorporated into its Integrated Water Resources Strategy, currently under development; 4) educating its citizenry; 5) preparing for the possible influx of climate refugees; 6) exploring, with its US Columbia Basin partners, the development of a Columbia River Compact; 7) investigating market-based strategies; and 8) implementing, updating and revising various laws, regulations, practices, and policies so as to better enable the state to cope with an uncertain water future.

Keywords: Global warming; Water resources; Snowpack; Groundwater recharge; Market strategies; Climate refugees

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POSTER

Simulation of Ground-Water Flow in the Willamette Basin and Central Willamette Sub-basin, Oregon

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ABSTRACT

The demand for water in the Willamette basin due to an increasing population and irrigation, and the full appropriation of tributary stream flow during the summer months creates an increasing demand for ground water in the region. An increase in ground water use potentially creates further depletion of stream flow, seasonal and long-term declines in ground water levels, and limitations due to low-permeability aquifers suitable for low demand uses only. In 1996, the U.S. Geological Survey and the Oregon Water Resources Department began a cooperative study to develop a quantitative conceptual understand of the ground water flow system of the Willamette River basin and central Willamette valley sub-basin. Regional and local models of the Willamette basin, and central Willamette sub-basin show a significant amount of discharge to the Willamette River is captured by wells located throughout the basin. Transient modeling of the central Willamette sub-basin indicate a buffering effect on smaller streams in the basin from the lower permeability Willamette silt unit when pumping from the lower sedimentary unit; however, this effect is diminished when pumping from the middle or upper sedimentary units. Temporal effects of pumping are demonstrated with most summer pumping initially being supplied by water released from aquifer storage; however, average annual discharge from and recharge to storage will go to zero over time, and total stream capture will equal average annual pumping. Aquifer geometry and stream incision control the ultimate effects of well pumping on streams in the Willamette basin.

Keywords: Ground water; Willamette River basin; modeling

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POSTER

Climate Warming, Soil Moisture Dynamics, and Water Budget Partitioning: Experimental Results from a Willamette Valley Ecosystem

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ABSTRACT

There is reasonable expectation that climate warming will accelerate the hydrologic cycle, resulting in greater evapotranspiration (ET) and reduced groundwater recharge (R) (or stream flow). Though qualitatively intuitive, quantifying these potential shifts in water budget partitioning is a contemporary challenge in hydrology, because the linkage between ET and R is strongly mediated by rainfall periodicity, vegetation, and soil moisture dynamics. This challenge has been accentuated by the Intergovernmental Panel on Climate Change, and is now being addressed primarily through model simulations, which have outpaced experimental efforts due to the overwhelming challenge of measuring the entire water budget in systems with known boundary conditions, and under forecasted alterations in surface air temperatures. We present new data from a controlled-chamber experiment that examines the combined responses of ET, soil moisture (θ), and R to imposed temperature alterations in a Willamette Valley grassland ecosystem. Temperature treatments include an average increase of 3.5°C, applied both symmetrically throughout the day, and asymmetrically such that daily minimum temperature is 5°C greater than ambient and daily maximum temperature is 2°C greater than ambient. Given the Mediterranean climate of this region, where rainfall and ET occur largely out of phase, we hypothesized that increasing surface air temperatures would accelerate and enhance plant growth and ET during the spring season, abbreviating the period when R occurs. Counter-intuitively, over a three year period we observed only modest enhancements of ET during the spring period under 3.5°C warming. The most salient effect was observed during the 2008 water year, when average-cumulative ET was 26-44% and 32-41% greater on April 30 under symmetric and asymmetric warming scenarios, respectively, than under ambient climate conditions. Corresponding acceleration of θ depletion was also observed, although there was no immediate effect on R. The cumulative effect of accelerated ET and θ depletion on R only became evident during late spring rain events (May-June), when average R generated under ambient climate conditions was 160-190% greater than under either warming scenario, although these events accounted for less than 6% of total R in any year. Collectively, the results demonstrate that annual water budget partitioning in Willamette Valley grasslands is unaltered by a 3.5°C increase in average air temperature. The temperature-driven enhancement of ET is modest and inconsequential for R during the short inter-storm time intervals typical during the spring. The contrasting seasonality of rainfall (and resulting R) and ET is the dominant climate feature determining annual water budget partitioning in the Willamette, and is here shown to effectively ameliorate the potential impact of a 3.5°C warming signal on the annual water budget.

Keywords: Willamette Valley; Water budget; Soil moisture; Climate warming

POSTER

Processing of Sediment Pulses Following the Removal of Three Small, Gravel-Filled Barriers

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ABSTRACT

The decommissioning of dams, as an approach to restoring longitudinal connectivity and to managing aging infrastructure, presents valuable opportunities for organized study of channel responses to sediment pulses. Experiments with physical and numerical models suggest that rivers process coarse sediment pulses primarily through dispersion. In contrast, translation appears to be a more important process when the sediment pulse consists of finer material, particularly when the grain sizes are finer than is typically present in the river. While the reported physical and numerical experiments have provided valuable insight into expectations channel dynamics, they are largely unconfirmed by field observations. To explore whether dispersion dominates the processing of gravel pulses in natural rivers, we investigated channel changes associated with three barrier removals in Oregon, ranging from very small (Oak Creek culvert, height = 1.5m), small (Brownsville Dam, height = 2.5m), to medium (Savage Rapids Dam, height = 12m) in size. Each trapped coarse sediment initially after construction, after which bedload passed over or through the barriers. Material behind the barriers was finer than the dominant grains downstream at Oak Creek and Savage Rapids, but was coarser than dominant channel grains at Brownsville. We present results from post removal bathymetric and substrate surveys for two years at Brownsville and Oak Creek, and one year at Savage Rapids.

Net deposition and scour, with error estimates, were calculated from surface differencing, both in the reservoir and downstream of the former barriers. We also characterized features of the stored sediment (e.g. ratio of reservoir D50 to averaged surface D50 in downstream reach, sediment volume) and the channel (e.g. Froude number, slope) to place these sites in context with other analyses of sediment pulses. Our results suggest that, at all sites, sediment is processed by both dispersion and translation, though dispersion appears to be the more dominant process. Further, the channels processed sediments rapidly, eroding substantial portions of reservoir material within the first two years following removal. These results suggest that, in the case of small to medium reservoirs filled with non-cohesive material, substantial aggradation will likely be limited to local areas directly downstream of the dam.

Keywords: Dam removal; Sediment pulses; Oak Creek